Sexual Behavior: A Seminal Peptide Stimulates Appetites

A new study shows that female fruitflies eat more after mating, and that a multi-functional peptide provided in the seminal fluid of their mates induces this behavior. These findings contribute significantly to our understanding of mating behaviors and resource allocation, and may provide insights useful for controlling the reproduction of insect pests.

Alex Wong and Mariana F. Wolfner

Romance and eating are linked in the public imagination in many cultures. Suitors woo the objects of their affection with boxes of chocolates, and jilted lovers may drown their sorrows in pints of ice cream. More seriously, a link between reproduction and food also makes biological sense, because of the extra energy required (especially in females) to produce gametes or progeny. A study reported in this issue of *Current Biology* [1] shows that mating stimulates female *Drosophila melanogaster* to feed, demonstrating a direct link between sex and nutriment. Carvalho *et al.* [1] narrowed down the stimulus for post-copulatory feeding to a seminal peptide that female flies receive from their mates. This work thus reveals a novel biochemical basis for the relationship between mating and eating.

Mating elicits a number of changes in female behavior and physiology. In *D. melanogaster*, these postmating changes include elevation of egg production and ovulation, decreased propensity to mate, storage of sperm, increased expression of some immune-response genes [2–4], and decreased life span (reviewed in [5,6]). Carvalho *et al.* [1] report a new post-mating response: females eat more after mating. The authors first visualized this directly by feeding the flies colored food — the fuller abdomens of mated females were more brightly colored than those of their unmated sibs — and confirmed these results with food containing a radioactive tracer. The latter experiments also showed that the increased accumulation of food in mated females was due to increased ingestion rather than decreased excretion.

Several aspects of mating could in principle trigger post-copulatory feeding. First, physical and behavioral cues that accompany copulation can influence a female's post-mating response. Second, sperm transferred to a female contribute to several of her post-mating responses, such as increased egg-laying and reluctance to remate. Third, molecules transferred from male to female, either as contact pheromones or in the seminal fluid, can affect the female. In *D. melanogaster*, seminal fluid includes approximately 80 'Acp' proteins, including peptides and prohormones which modulate several post-mating changes in post-copulatory females (reviewed in [5,6]).

Carvalho *et al.* [1] found that the mates of males who provided sperm but not Acps [7] failed to eat more, suggesting that the stimulator of feeding must be an Acp. By mating females to males lacking the 36 amino acid Acp (Acp70A) called sex peptide [8], Carvalho *et al.* [1] then showed that receipt of sex peptide is necessary for a female's post-copulatory eating binge. They confirmed this by showing that females engineered to express sex peptide showed an elevated level of food intake even without mating. Thus, this single Acp is both necessary and sufficient for increasing feeding by mated female flies. These findings add another important role for sex peptide, which was previously known (reviewed in [9]) to regulate post-mating egg production, receptivity behavior, immunity-gene expression [4], and longevity [10] in mated females.

These results [1] provide much food for thought. First, they prompt the question of how sex peptide could cause so many changes in mated females. Do a few initial actions lead to multiple consequences? For example, studies in several animals, including *Drosophila*, suggest interaction between lifespan and nutrition [11,12]. Given that sex peptide increases feeding, and is at least partially responsible for the decrease in longevity of mated *D. melanogaster* females [10], could increased food intake underlie the sex-peptide-dependent part of the longevity cost-of-mating in this organism? Similarly, as diet is known to affect the rate of egg production in *D. melanogaster*, such that poor quality food results in low rates of oogenesis [13], might increased food intake partially underlie sex peptide's stimulation of oogenesis? Alternatively, might the increased food intake be a consequence of the energy demands of increased oogenesis triggered by sex peptide?

To address these cause-and-effect questions, it will be important to elucidate the downstream pathways through which sex peptide acts. One possibility is that sex peptide might act through endocrine effectors, of which there are two promising candidates: juvenile hormone and the insulin pathway. Previous experiments showed that sex peptide increases the production of juvenile hormone *in vitro* [14], and topical application of juvenile hormone mimics sex peptide's effects on egg production (but not on receptivity [15]). Insulin has been implicated in several phenomena relevant to the mating response, particularly the regulation of oogenesis and lifespan in response to nutritional state [11,13]. Relatedly, it will be interesting to see how (and whether) sex peptide effectors feed into pathways that regulate appetitive behaviors (reviewed in [16]).

Another fascinating implication of the finding that sex peptide regulates eating in mated females arises from the consideration that

organisms must sometimes choose between allocating their limited resources to somatic maintenance or to reproduction (reviewed in [17]). For example, such a shift might underlie the downregulation of some metabolic genes in *D. melanogaster* females after mating [2]. Increased reproduction can come at a cost to an individual's survival; on the other hand, relatively high investment in the soma can result in a cost to reproduction. Previous studies in insect reproduction offer several precedents for the idea that males might help mitigate such tradeoffs in their mates. Males may provide females with nuptial gifts, for example of secretions from male glands (reviewed in [5]), of specific compounds such as salt [18], or elements such as phosphorus [19] that can nourish the female and assist with egg provisioning. Carvalho *et al.*'s [1] results suggest a new way in which a *Drosophila* male can influence resource input into his mate: he simply induces her to eat! Increased feeding may in turn allow a female to put relatively more investment into egg production, or to increase resources available for reproduction without changing relative resource allocation patterns.

Finally, the results presented here may merit consideration in practical applications, for example in the control of some disease vectors. Food plays a very important role in mosquito reproduction: blood meals are nearly always essential for the female mosquito to produce eggs, and some studies (reviewed in [20]) have shown that mating status can impact a female mosquito's behavior and physiology. Given that a male-derived peptide can change the feeding behavior of *D. melanogaster* (a Dipteran, as are mosquitoes), might a similar phenomenon operate in any mosquito? If so, it might help us to understand and possibly control the transmission of some vector-borne diseases.

Carvalho *et al.*'s [1] results leave us hungry for more. Mating-induced eating represents a novel post-copulatory behavior, which to our knowledge has not been demonstrated in any other species. The topic is made all the more 'appetizing' by its broad range of implications: to regulation of post-mating behaviors, life-history trade-offs and, possibly, for practical applications.

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Myopia: The Importance of Seeing Fine Detail

Eye growth and myopia development are controlled by the retina. What properties of the image tell the retina how the eye should grow? A recent study has shown that, in chickens, fine details are necessary to prevent the development of myopia. Should we carefully avoid any defocus to avoid becoming myopic?

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The organ with the highest geometrical precision in the body is most likely the eye: for a human to be normal-sighted (or emmetropic), which means being able to see sharply at far distances, the geometrical length of the eye must be matched to its optical focal length with a precision of about 0.2 percent, less than the thickness of an eyelash. An increase in eye length of just 0.1 millimetre is sufficient to cause a measurable decline in visual acuity for distant objects — myopia. When this happens, the sharpest image projected by cornea and lens is formed, not on the photoreceptor layer of the retina, but in front of this layer. Myopia is quite frequent